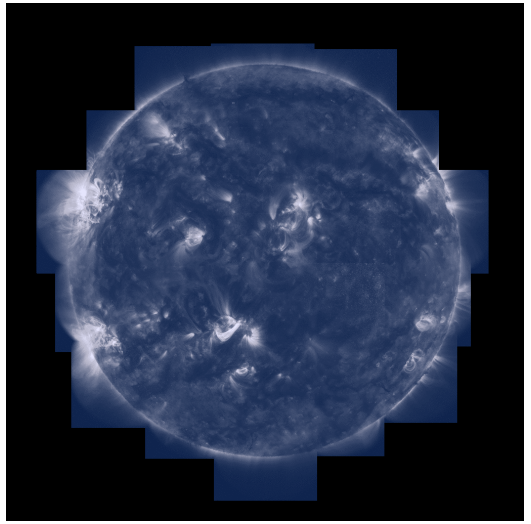
Section 7

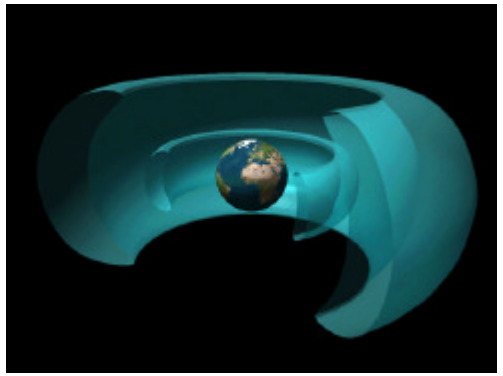
Theory and Modeling

Theory and Modeling

The LWS program is targeted toward the research needed to do the following:

- Improve understanding of space weather and solar variability and its effect on long-term climate change
- Enable and develop improved specification models and predictive capability
- Cover the vast region from the solar atmosphere to Earth's ionosphere

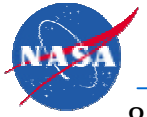




Theory and Modeling Program

The LWS program will employ theory and modeling to:

- Identify and understand variable sources of mass and energy coming from the Sun that cause changes in the environment with societal consequences, including the habitability of Earth, use of technology, and the exploration of space
- Identify and understand the reactions of geospace regions whose variability has societal consequences and impacts
- Quantitatively connect and model variations in the energy sources and reactions to enable a comprehensive forecasting capability on multiple time scales
- Extend the knowledge and understanding gained in this program to explore extreme solar-terrestrial environments and implications for life and habitability beyond Earth



Theory and Modeling Tasks

The LWS program will perform theory and modeling tasks to:

- Assess the solar role in climate change
- Provide better space environment specifications
- Understand and enable predictions of solar activity with potential space weather consequences
- Track geo-effective structures and particles through the heliosphere and determine their evolution and characteristics at Earth
- Understand the evolution of magnetospheric particles and fields in response to solar wind and ionospheric interactions
- Determine the structure and dynamics of the ionized upper atmosphere, including the neutral gas and its electric currents, as influenced by solar and magnetospheric input
- Support LWS missions
- Utilize and assimilate measurements from LWS spacecraft and other relevant data sources

Theory and Modeling Implementation

The LWS theory mission approach will be to build a program focused on LWS needs by:

- Building on current research activities to provide overall LWS research coordination, together with data analysis activities:
  - Requires detailed planning by science definition teams
  - Combining large-scale, comprehensive, and physics-based models
  - Open theory and model policy
- Developing new theories and models where required:
  - Empirical approaches
  - Innovative physics-based theories and models
- Developing tools for synergistic modeling and data assimilation
- Partnering with other agencies
- Employing the Community Coordinated Modeling Center (CCMC) as a focal point

The challenges and related approaches for this proposed program are delineated in the charts that follow.

Solar Interior and Atmosphere

The challenge is to develop an accurate understanding and description of:

- Solar energetic particle acceleration near the Sun [a,s]
- Long-term luminosity variations [g]
- Transient radio, UV, and x-ray bursts [a,s]
- Magnetic field generation and its evolution in the interior, surface layers, and atmosphere [a,s]
- Coronal heating and solar wind acceleration [a,s]
- Conditions conducive to flare genesis [a,s]
- Formation and characteristics of CMEs [a,s]

Approaches and research topics will include:

- Dynamo theory
- Three-dimensional global MHD models
- MHD using theory-based micro-physics modules
- Three-dimensional local MHD models
- Kinetic shock models on sub-gridscale
- Magnetic field models
- Nonlinear predictive approaches
- Models using assimilation of spacecraft and ground observations
- Solar oscillation theory

a: astronaut safety
s: spacecraft safety
g:global change
direct/indirect impact

Heliosphere

The challenge is to develop an accurate understanding and description of:

- Solar wind stream structure and topology of the heliospheric current sheet [a,s]
- Heliospheric magnetic field structure and topology [a,s,g]
- Solar wind evolution in interplanetary space [a,s]
- Propagation and structure of CMEs and magnetic clouds, including shock location and properties [a,s]
- Particle acceleration at interplanetary shocks [a,s]
- Propagation, spectra, and self-consistent wave generation of energetic particles [a,s]

Approaches and research topics will include:

- High-resolution, three-dimensional MHD models
- Quasi-fluid theory of the dissipation scales
- Shock physics and disturbance propagation
- Particle acceleration and transport modules
- Boundary conditions at the Sun
- Assimilation of spacecraft observations

a: astronaut safety
s: spacecraft safety
g:global change
direct/indirect impact

Magnetosphere

The challenge is to develop an accurate understanding and description of:

- Solar wind coupling [a,s]
- Structure of boundary layers [a,s]
- Magnetic fields and currents, including polar cap size [a,s]
- Energetic particle acceleration processes and flux levels [a,s]
- Energetic particle entry and losses [a,s]
- Plasma density, energy spectrum, and composition [a,s]
- Sequences of activity, including storms and substorms [a,s]
- Interaction with the ionosphere by field-aligned currents and electric fields [a,s]

Approaches and research topics will include:

- Three-dimensional MHD models coupled to solar wind and ionosphere using physics modules
- Kinetic physics models for foreshock, magnetopause, and magneto-tail current sheet
- Inner magnetosphere particle drift models, including electric field models
- Particle transport models with improved magnetic field and wave activity theories
- Apply electric fields and particle fluxes from ionosphere
- Particle specification and nonlinear predictive approaches
- Models assimilating spacecraft and ground observations

a: astronaut safety
s: spacecraft safety
g:global change
direct/indirect impact

Ionosphere/Thermosphere

The challenge is to develop an accurate understanding and description of:

- Ionospheric and plasmaspheric density, temperature, and composition [a,s]
- Variability due to coupling to lower atmosphere and solar photon variations [a,s,g]
- Ionospheric conductivity [a,s]
- Ionospheric electric fields and currents [a,s]
- Plasma irregularities [a,s]
- Upper atmosphere scale height, composition, and winds [a,s,g]
- Ionosphere-magnetosphere plasma exchange and other coupling processes [a,s]

Approaches and research topics will include:

- Multi-fluid models of dynamics, chemistry, energetics, and electrodynamics
- Energetic particle acceleration and transport theories
- Photon emission theories
- Scintillation predictions based on local parameters
- Ion-neutral coupling model
- Ground-induced current model
- Models assimilating spacecraft and ground observations

a: astronaut safety
s: spacecraft safety
g:global change
direct/indirect impact

Global Change

The challenges are to:

- Understand the climatic impact of solar radiation variations
- Understand the climatic impact of variations of the Earth's internal magnetic field
- Understand the causes of variations in solar total and UV irradiance
- Describe the middle atmospheric impact of solar UV variations
- Understand the atmospheric changes by solar and magnetospheric energetic particle precipitation
- Understand the atmospheric changes by cosmic ray precipitation and their modulations by the interplanetary and magnetospheric magnetic fields

Approaches and research topics will include:

- Solar heat transport and radiative transfer models
- General circulation modeling of the coupled upper, middle, and lower atmosphere
- Atmospheric electric circuit models
- Heliospheric magnetic field and energetic particle propagation models
- Physics-based source terms for climate models